Lunar tides in the Mesosphere over Ascension Island (8° S, 14.4° W)

D. J. Sandford, N. J. Mitchell

Ann. Geophys., 25, 9–12, 2007
www.ann-geophys.net/25/9/2007/

Annales Geophysicae

Lunar tides in the Mesosphere over Ascension Island (8° S, 14.4° W)

D. J. Sandford and N. J. Mitchell

Centre for Space, Atmospheric & Oceanic Science, Department of Electronic and Electrical Engineering, University of Bath, Bath, BA2 7AY, UK

Received: 27 November 2006 – Accepted: 20 December 2006 – Published: 1 February 2007

Abstract. A meteor radar has been used to measure the horizontal winds in the equatorial mesosphere and lower thermosphere over Ascension Island (8.0° S, 14.4° W). A 5-year data set covering the interval 2001–2005 over the height range 78–100 km is considered. The lunar M_2 tide is clearly evident in the data and reaches amplitudes as large as 11 ms^{-1} in the meridional component and 6 ms^{-1} in the zonal component. These are the first observations of the lunar tide made over the equatorial Atlantic sector. Comparisons of the observed seasonal behaviour with the model of Vial and Forbes (1994) reveals good agreement, but the observed amplitudes are generally larger and there is a systematic phase difference of $\sim$2 h with the observed phases lagging the model. Comparisons with observations made at other equatorial sites suggest the presence of non-migrating lunar M_2 tides and/or significant inter-annual variability.

Keywords. Meteorology and atmospheric dynamics (Climatology; Middle atmosphere dynamics; Waves and tides)

1 Introduction

Lunar tides in the atmosphere are difficult to study because of their small amplitudes and proximity in frequency to the semi-diurnal solar tide. The largest-amplitude mode appears to be the migrating lunar M_2 semidiurnal tide of period 12.416 to 12.424 h. Further, the frequencies of the lunar M_2 and solar S_2 tides are very close. Extended data sets are thus required to provide the spectral resolution necessary to resolve the M_2 and S_2 components.

The equatorial lunar M_2 tide has been previously observed over only two sites: Christmas Island (2° N, 157° W) and Jakarta (6° S, 253° W) (Stening et al., 1997, 2003). The results presented here from over Ascension Island (8° S, 14° W) are thus approximately in the centre of the 264° of longitude between these sites and thus complement these earlier studies. Few modelling studies of the lunar tides in the MLT region have been reported, although Vial and Forbes (1994) presented zonal-mean results in terms of horizontal winds, temperature and geopotential height.

Correspondence to: D. J. Sandford
(d.j.sandford@bath.ac.uk)

2 Data and analysis

The data used here have been collected by a meteor radar on Ascension Island (8.0° S, 14.4° W) in the equatorial Atlantic. The radar is a SKiYMET system, similar to that described by Mitchell et al. (2002). It operates at a frequency of 43.5 MHz. Peak power is either 12 or 6 kW. Here we consider data recorded from October 2001 to March 2006. Horizontal winds at heights of 78–100 km are calculated in independent height gates of 5, 3, 3, 3, 3 and 5 km. The mean height of the individual meteors detected within each height gate yields height-gate centres at 81.1, 84.6, 87.5, 90.4, 93.3 and 96.8 km.

Monthly-mean tidal amplitudes and phases are calculated for each height gate using the least squares method of Malin and Schlapp (1980). In each height gate, the winds are assumed to consist of a background flow and sinusoidal solar and lunar tidal oscillations at periods of 24, 12, 8, 6 and L hours, where L is the period of the lunar M_2 tide calculated for a particular month. The value of L varies slightly with the lunar age between $\sim$12.416 and 12.424 h (the lunar age is time since the last new moon). Note that the period of the lunar M_2tide at a given time is 2τ, where τ is the lunar time and is given by $\tau = t - \nu$, where t is the solar time and ν is the lunar age. Lunar age is a measure of the phase of the Moon, where $\nu = 0$ signifies new moon (Stening et al., 1997, 2003). This method has been used to successfully by Sandford et al. (2006) and Stening et al. (1997, 2003). Because high spectral resolution is required to separate the Lunar M_2 and

AnGeo Communicates

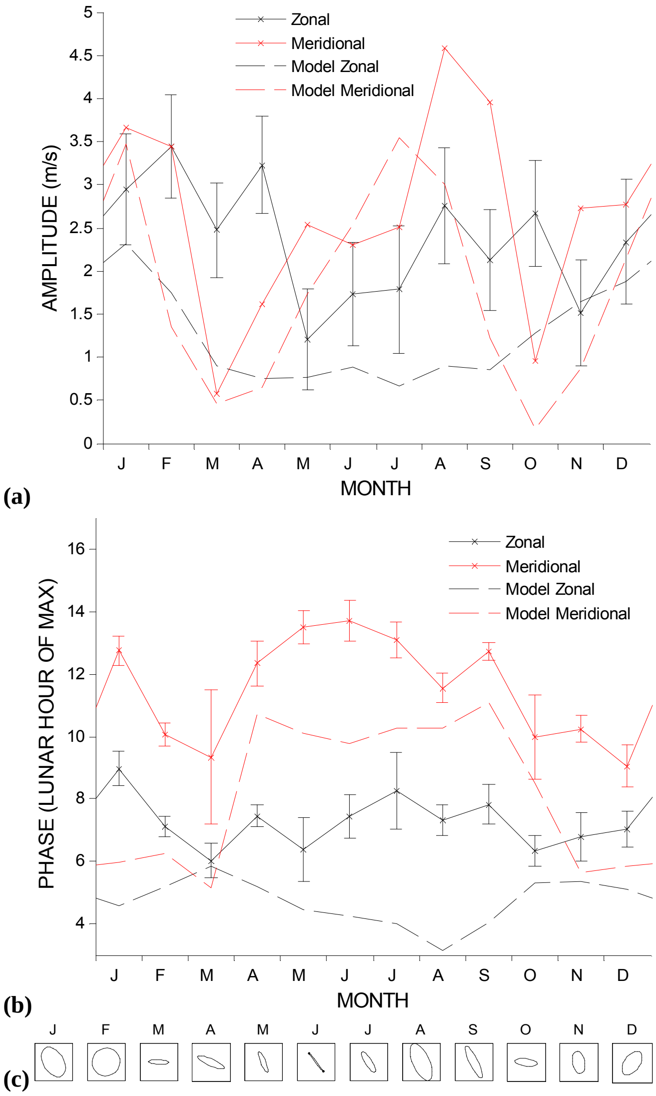

Fig. 1. Monthly-mean amplitudes, phases and hodographs of the Lunar M_2 tide calculated from Ascension Island data (2001–2005) vector averaged to produce the seasonal variation indicated by the solid lines. Dashed lines indicate results from Vial and Forbes (1994) model. Black lines represent the zonal component and red lines the meridional component.

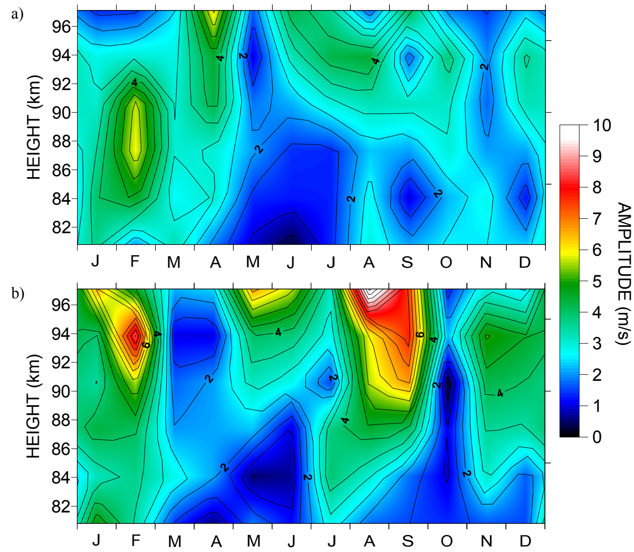

Fig. 2. Contour plot of the Lunar M_2 tidal amplitude calculated form monthly-mean amplitudes (vector averaged to give the seasonal variation) of zonal and meridional wind data over the period 2001–2005 from the Ascension Island meteor radar. Colour scale indicates amplitude.

Solar S_2 tides, only results from months with more than 16 complete days of data were accepted. This criterion means that 11 out of 54 months of data were discarded.

3 Results

Monthly-mean tidal amplitude and phase were calculated in each height gate for each of the above tides for all of the available months of the 5-year dataset. The monthly-means for each month from successive years were then vector averaged to yield a composite year. Figures 1a, b present the resulting zonal and meridional amplitudes and phases, respectively, averaged over all six height gates, i.e., 78–100 km. The monthly-mean amplitudes are seen to be mostly between ∼1.5 and 3 ms^{-1}. During most of the year the meridional amplitudes are larger, but around the equinoxes the zonal amplitudes are larger. The meridional amplitudes exhibit two distinct equinoctial minima. The phases of Fig. 1b reveal that the zonal component leads the meridional throughout the year, i.e., an anticlockwise rotation with time. The phase difference between the two components is ∼3 h in Southern-Hemisphere (SH) summer (November to March) and changes at the equinoxes to values as large as six hours in the winter months. To more easily visualise the relationship of amplitude, phase and polarisation, Fig. 1c presents hodographs of the monthly-mean properties. As can be seen from the figure, SH summer months are more circularly polarised, the transition regions (March and October) are elliptically polarised towards the zonal and for the majority of the rest of the year (May–September), the tide is elliptically polarised in anti-phase.

The monthly-mean amplitudes in each height gate are presented as contours in Figs. 2a, b for the zonal and meridional components, respectively. The contours reveal that in most months the tidal amplitudes increase with height to values as large as ∼10 ms^{-1} at heights of ∼97 km. As suggested by the all-height-gate means of Fig. 1, the wintertime and summertime meridional amplitudes are generally larger than the zonal ones. Around the equinoxes, the amplitudes fall to very small values, often <2 ms^{-1} at all heights. Interestingly, in February and near the autumnal equinox the zonal

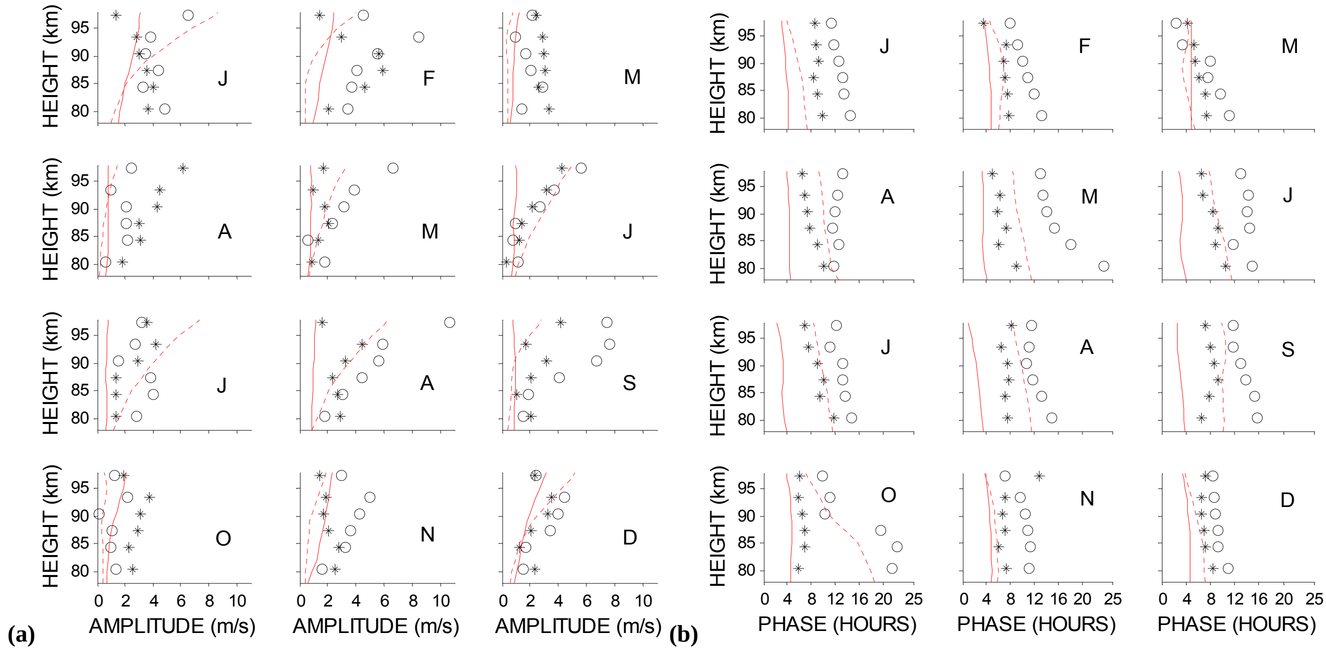

Fig. 3. Monthly amplitude and phase plots of the Lunar M_2 tide over Ascension Island. Black symbols indicate tidal amplitudes calculated from the Ascension Island meteor radar over the period 2001–2005 and the red lines indicate results from the Vial and Forbes (1994) model. Solid lines show the zonal (stars) component and dashed show the meridional (circles).

amplitudes display a short-lived maximum that peaks at a height of ~88–90 km. This feature is reminiscent of the local autumnal maxima of the 12-h solar tide sometimes observed at this and other latitudes.

Figure 3a presents height profiles of zonal and meridional amplitude for each month of the Ascension Island observations along with the corresponding predictions of the Vial and Forbes (1994) model. In both components, the observed amplitudes are either approximately similar to or significantly larger than the model predictions. The differences are largest in autumn (February to April) and spring (August to September) where the observed amplitudes rise toward values near 10 ms^{-1} at the upper heights, but where the model predictions are usually somewhat smaller.

Figure 3b presents a similar analysis of the phases. The observed phases generally decrease with height, corresponding to an upwardly-propagating tide. The zonal phase leads the meridional by amounts varying from <1 lunar hour in March to ~10 lunar hours in May. The observed zonal phases lag the model phases at all heights and in all months. The differences are largest around the summer solstice (January) and in winter and early spring (June to September) when the differences can exceed 6 h. The differences are rather less in the case of the meridional phases. Uncertainties in the measured phases are not shown for reasons of clarity. However, the mean uncertainty in phase over the entire ensemble of monthly data is 1.3 h and the largest uncertainties occur when the amplitudes are small.

The variation of tidal phase with height allows calculation of the vertical wavelength for each month (not shown). In the zonal and meridional components the vertical wavelengths are generally between ~50 and 80 km but range from a minimum of 12±2 km in October to a maximum of 150±60 km in February. The model predicts meridional wavelengths roughly comparable to these values, but predicts significantly larger zonal vertical wavelengths (>150 km). The observations over Ascension Island and the model both exhibit vertical wavelengths that can differ between the two components.

4 Discussions

Only two studies of the lunar M_2 tide in the low-latitude MLT region have been reported. Firstly, Stening et al. (1997) presented MF-radar measurements made over Christmas Island (2° N, 203° E) in the Pacific sector from 1990–1993. The amplitudes were broadly similar to those reported here. However, Stening et al. observed a systematic, year-long, 6-h phase difference between the zonal and meridional components and saw no equinoctial transition, unlike the seasonally-varying meridional phases reported here. Measured in lunar hours, there is also a systematic phase difference of ~3 h in the zonal components, with Ascension Island lagging Christmas Island.

Secondly, Stening et al. (2003) reported observations made by meteor radar over Jakarta (6.4° S, 107° E) between

1987 and 1988. The monthly-mean amplitudes at Jakarta are similar to those over Ascension Island during summer, but at other times the latter amplitudes are larger, particularly during late winter (August and September). Stening et al. also noted that the phase relationship between the zonal and meridional components of the tide over Jakarta in southern spring and summer was more characteristic of a northern hemisphere lunar tide – a type of behaviour not seen over the slightly more southerly Ascension Island. Comparing Jakarta to Ascension Island, in summer and autumn the zonal phases agree to within ∼2 h. However, in SH winter and early spring (June to September) the phases over Ascension Island do not change significantly, whereas at Jakarta the zonal phases changed by ∼6 h. During this time the zonal phases over the two sites are thus in approximate anti-phase. In contrast, the meridional phases have a similar seasonal progression with a systematic difference of ∼4 h (Jakarta leading Ascension Island).

Stening et al. (2003) also examined the latitudinal behaviour of the equatorial lunar M_2 tide in a seasonal version of the Global Scale Wave Model. The model suggests zonal phases vary little with latitude throughout the year within 10° of the equator. All three sites considered here should thus see similar zonal phase behaviour – in contrast to the results described above. Meridional phases also vary little with latitude, except in SH autumn (March–May) when they are in approximate anti-phase across the equator. The zonal phases observed at 90 km over Ascension Island are actually very close to these predicted GSWM phases (less than one hour difference in 10 months of the year). The meridional phases only agree well between April and September.

Possible explanations for the large differences between Ascension Island and the other two sites include: 1) Interannual variability, because the various studies are not contemporaneous. 2) Biases between different radars/techniques which may make direct inter-comparison of observations difficult (e.g. Manson et al., 2004). However, such biases are more likely to affect comparisons of tidal amplitude rather than the phases considered here. 3) Non-migrating lunar M_2 tides may be present, resulting in significant longitudinal variations of amplitude and phase. Vial and Forbes (1994) suggests that such non-migrating modes are significant, although they do not present results for low latitudes in the MLT. The systematic nature of some of the observed phase differences is in agreement with what might be expected in the presence of non-migrating modes.

5 Conclusions

The lunar M_2 tide in the MLT over Ascension Island (8.0° S, 14.4° W) can reach amplitudes of $\sim$11 ms^{-1}. The amplitudes often increase with height. A clear seasonal behaviour exists with maximum amplitudes in SH winter and late summer. Agreement is good with the Vial and Forbes (1994) model, except that larger amplitudes are observed than predicted (up to factor two) and there is a systematic phase offset of ∼2 h with the observations lagging the model.

Comparisons with observations made in earlier years over Christmas Island and Jakarta show a reasonable agreement in the case of tidal amplitudes but the phases exhibit very significant differences – sometimes become so large they result in an anti-phase relationship between Ascension Island and Jakarta. Non-migrating lunar tides may account for some of these differences.

Acknowledgements. Model data of the Vial and Forbes Lunar Tidal model was kindly supplied via the CEDAR database.

Topical Editor U.-P. Hoppe thanks one referee for his/her help in evaluating this paper.

References

Malin, S. R. C. and Schlapp, D. M.: Geomagnetic Lunar Analysis by Least-Squares, Geophys. J. Roy. Astronom. Soc., 60, 409–418, 1980.

Manson, A. H., Meek, C. E., Hall, C. M., Nozawa, S., Mitchell, N. J., Pancheva, D., Singer, W., and Hoffmann, P.: Mesopause dynamics from the Scandinavian triangle of radars within the PSMOS-DATAR Project, Ann. Geophys., 22, 367–386, 2004, http://www.ann-geophys.net/22/367/2004/.

Mitchell, N. J., Pancheva, D., Middleton, H. R., and Hagan, M. E.: Mean winds and tides in the Arctic mesosphere and lower thermosphere, J. Geophys. Res.-Space Phys., 107(A1), 1004, doi:10.1029/2001JA900127, 2002.

Sandford, D. J., Muller, H. G., and Mitchell, N. J.: Observations of the lunar tides in the mesosphere and lower thermosphere at Arctic and middle latitudes, Atmos. Chem. Phys., 6, 4117–4127, 2006,
http://www.atmos-chem-phys.net/6/4117/2006/.

Stening, R. J., Schlapp, D. M., and Vincent, R. A.: Lunar tides in the mesosphere over Christmas Island (2 degrees N, 203 degrees E), J. Geophys. Res.-Atmos., 102, 26 239–26 245, 1997.

Stening, R. J., Tsuda, T., and Nakamura, T.: Lunar tidal winds in the upper atmosphere over Jakarta, J. Geophys. Res-Space Phys., 108(A5), 1192, doi:10.1029/2002JA009528, 2003.

Vial, F. and Forbes J. M.: Monthly Simulations Of The Lunar Semi-Diurnal Tide, J. Atmos. Terr. Phys., 56, 1591–1607, 1994.